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# ANALYSIS OF STUDIES OF THE PARAMETERS OF THE WORKING BODY OF THE COMBINED UNIT FOR PRE-SOWING TILLAGE AND SEED SOWING

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***Abstract.*** The article discusses the idea of a scientific and technical project won within the framework of a competitive application of the Ministry of Education and Science of the Republic of Kazakhstan for 2020-2022 to develop a combined tool adapted to the soil and climatic conditions of the Southern region of Kazakhstan for pre-sowing tillage and sowing seeds in order to increase their yield, reduce the cost of their cultivation, preserve and increase soil fertility.
As a result of the analysis of studies on the selection of types and justification of parameters of the working bodies of a combined unit for pre-sowing tillage with simultaneous sowing of seeds with active working bodies, it is possible to open up a wide opportunity to create combined machines combining tillage operations with simultaneous planting of various crops of the working bodies of a milling cultivator.

***Keywords:*** high-performance combined unit, strip-till cultivation, soil, tiller, secondary tillage, active working elements.

## 1. Introduction

Analysing the research of the parameters of the working body of the combined unit for pre-sowing tillage and sowing seeds of domestic and foreign scientists, we see that in terms of the quality of the technological process, tillage machines with active working bodies have no equal in soil preparation and processing of row crops. Tillage machines with active working bodies create a high quality of the treated layer, since in the process of cutting off small chips from the soil layer, the upper layers of the soil are simultaneously mixed with fertilizers and the plant residues are evenly sealed (Aushev, 2014; Gorbachev, 2013; Dalin, 1941; Nesterov, 2011; Smailov, 2002).
The results of analysing contemporary advances in engineering and technologies have demonstrated that a mechanical method, employing tillage machines with active working elements, is a principal method for cultivating soils. That is why researchers keep searching for the ways of enhancing tillage equipment.
The knives of the working elements of soil-cultivating tillers have different shape, hence, the profiles of knives also differ from each other. Thus, the effect of variously shaped profiles of

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knives on the energy intensity of rotary cultivation and the quality of breaking up should be additionally studied (Panov & Vetokhin, 2008).

It is a common fact that crop farming, growing of cereals, technical, and vegetable crops form the basis of agricultural production. To have a good harvest, of importance is to improve the quality of preparing soil, by creating favourable conditions for the growth and development of plants. Soil cultivation in agricultural industry is among energy-intensive processes (Kokorin & Korepanov, 2008; Korshun, 2002). To increase the quality of preparing soil, there is a need for finding efficient energy-saving technologies of soil cultivation and enhancing the structures of the working elements of tillage machines.

In Germany, S-shape working elements have been considered the most efficient. Foreign scientists have mostly focused upon experimental studies of rotary tillers on justification of their most rational structural and kinematic parameters. To date, the working elements of several types, which meet soil and climate conditions of each country, have been used abroad for various structures of tillers. Tillers with G– and T–shape knives have mostly been employed in Holland, Italy, and Germany. Continuously curved vertical tillers with screw-type angling of knives relative to the rotation plane have found wide application in Japan. For secondary tillage in the countries of Western Europe there has become most favoured a “Rotavator” tiller, made by the “Howard” Company from England, which produces more than 10 of its modifications for different purposes in four series, depending on the tractor power and soil type. A “Kuhn” company from Germany also produces a broad range of soil-cultivating tillers, intended for various working conditions, of EL and DK series, with horizontal tiller rotor and HR series with vertical tiller rotors (Korshun, 2002; Belov, 2019; Ramazanova, 2016; Kurbanov R.F., Khodyrev, 2016; Gadzhiev, 2008; Chatkin, 2008; Kupryashkin, 2013; Karnaukhov, 2009).

In Poland, vertical tillers Hermez for tractors of 1.4 thrust class, made by Unia Group, have been widespread, which can be used to work with both moderate, and heavy soils (Dranyaev et al., 2017) without clogging and barring of working knives. They are made of robust boron-bearing fine-grained steel, knives are securely fastened with protection against barring. Two one-pass operations. Vertical tillers Hermez can be combined with Polonez seed planters in lift-type seeding combinations and employed for secondary tillage and sowing.

Rotating 280mm long knives cut segmented soil layers and mix them in a closed space of the working area. The cultivation depth is regulated by side covers, installed using bolts on the flank of the unit. Side covers are also employed to ensure comfort and safety of operation (Akimov et al., 2017; Bolokhin et al., 2016; Belov et al., 2019).

A lift-type tiller FN-1.2 is produced by the “Ryazselmash” LLC. Working elements of the tiller are driven by a power take-off shaft (PTS) of a tractor, the grasp width is 1.2m, working speed is 3km/h, capacity is 0.36 ha/h, ripping depth is 12cm. It is aggregated with tractors MTZ-50, T-40, K-20, T-30, T-25. The tiller is used in all natural and climatic zones for preplanting cultivation on small-contour fields.

The same factory manufactures universal machines UMVK-1.4, UMVK-2.8 to prepare soils for potato, vegetables, and other crops.

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UMVK-1.4 machine performs the following technological procedures: preparation of soils prior to planting potato (vegetables) with formation of a small-clod structure at the depth of up to 15cm, tillage of ridges with 70-75cm spacing; inter-row cultivation of seedlings with simultaneous ripping, weed destruction and formation of ridges up to 28cm in height; cutting and mulching of shaw and plant residues; introduction of dry mineral fertilisers. The machine has up to 0.8 ha/h capacity, can be aggregated with tractors of 1.4 thrust class (Dementiev, 2017; Koval', 2010; Slavkin et al., 2019; Gadzhiev et al., 2013; Bolokhin et al., 2011; Chatkin, 2008; Kupryashkin, 2013; Kupryashkin, 2011).

The UMVK-2.8 universal machine performs pre-planting preparation of soil prior to sowing potato, and other crops; ridge tillage for planting potato, and other crops; ripping (rotary tillage) of soil in the spaces between rows of potato, cultivated with 70x75cm row spacing with simultaneous formation of ridges 12-14 days after planting; ragging of shaw and plant residues with their laying into spaces between rows.

The "Rabewerk" Company (Germany) has designed a family of rotary cultivators for rapeseed, beetroot, corn, and other crops with horizontal rotation axis of working elements of R, LR, and SR series, and a family of circular harrows with vertical knives of MKE, PKE, and SKE series.

PKE is intended for ripping during early agrotechnical terms without carrying over substrata to the surface. It is aggregated with the MTZ-80/82 tractor and has the following specific features: reinforced structure of a carrying sump, actuator, and working elements; ease of maintenance and adjustment at a high reliability; potential selection of an optimal mode of rotary tillage for high-quality preparation of any type of soil, even when there are stones. The PKE-300 cultivator works well and efficiently with MTZ-80/82 tractors (Zhuk, 1978).

The "Bush Hog" Company (USA) has created three versions of row tillers (HAM, HTS, and RTH), designed for cultivation of fruit and vegetable plantations. The models differ from traditional structures in a larger diameter of tiller rotor, which defines a 15-20cm cultivation depth.

The "Celli" Company from Italy manufactures a tiller, made in three modifications with a 1.55-3.05m grasp width. The tiller is equipped with blade-shaped working elements, mounted on 27 oblique square flanges of a tiller rotor.

As opposed to the latter, horizontal-rotary cultivators CELLI are more efficient and advanced. These cultivators "actively" prepare soil, driven by a tractor's PTS. Knives, curved at a right-angle and/or rounded, directed (towards one another) or brought apart to the opposite sides inside (Matyashin, 1988), can be installed on a rotor.

To ensure maximum quality of secondary tillage, cultivators can be equipped with a rotor with straight knives and/or teeth, instead of standard bent knives. In case of such configuration, cultivators are re-equipped with a special back plate for enhanced soil levelling and a rear packing wheel (tube and/or needle-like and/or wheeled and/or helically-formed) to enhance finishing levelling and create light compaction of a topsoil.

It is recommended that a gear box of such cultivators should be equipped with gears to increase the speed of rotor spinning (usually, more than 300 rpm).

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All the cultivators in basic/standard configuration are equipped with side slippers for precise adjustment of the soil cultivation depth.

Vertical-rotary cultivator Celli is used for continuous secondary tillage to the depth of up to 30cm (without active mixing of horizontal soil layers) with further levelling and rolling down.

A major obstacle to introducing cutting-edge technologies of growing agricultural crops in the south of Kazakhstan lies in the lack of the technical means of combined tools for high-quality surface tillage and sowing.

Such machines and tools, made abroad, have high metal intensity; their working elements are not necessarily adapted to soil and climate conditions of the Southern Kazakhstan; tractors of a 14-50kN thrust class are required to work with them. These machines are expensive; hence, they are in no demand on medium and small peasant farms. Hence, a need arises for developing a combined unit with working elements, adapted for a work on the regional soils with different mechanical compositions and various degree of cloddiness, density, and humidity. An essential distinction of our idea will lie in creating a small-size combined unit for farm enterprises, aggregated with tractors of 0.6 and 1.4 HP thrust class and executing the following operations: strip-till (tiller) seedbed preparation, planting of vegetables seeds, inter-row cultivation.

Hence, the study aims to develop and manufacture an experimental specimen of a combined unit for secondary tillage and sowing, and to conduct its preliminary tests.

The fundamental distinction of our idea will lie in creating a small-size combined unit for farm enterprises, aggregated with tractors of 0.6…1.4kN thrust class and executing the following operations: strip-till (tiller) seedbed preparation, planting of vegetables seeds, inter-row cultivation.

When introducing a combined unit for soil preparation and sowing, the number of machine-tractor aggregates' (MTAs) passes across the field will decrease, energy and materials intensity during technological procedures will decrease by 54.6%, specific capital and operational costs - by 61.4%, labour and POL costs - by 56.6%, as compared to single-step machines.

## 2. Materials and methods

Tillage machines with active working elements afford an ample opportunity to create multiple-purpose machines, which combine soil preparation and simultaneous sowing of various agricultural crops (Aushev, 2014; Gorbachev, 2013).

Such a principle has been applied to design a variable-row seed planter with active G-shape working elements, which, as Professor A.D. Dalin wrote (Dalin, 1941), must comply with such requirements as:

- plant residues' mincing and uniformly embedding them in depth, and mixing topsoil with fertilisers;
- active working elements must ensure high quality of soil cultivation, and a change in the speed of rotary motion of a tiller rotor and the forward speed of a unit might change the degree of breaking up;
- tillage machine with active working elements must contribute to reducing thrust resistance and energy intensity of soil cultivation process and increasing the unit capacity;

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- knives of tillers must not stick and be clogged even on clay soils, due to high cutting speeds.

Design structures of present-day soil-cultivating tillers have numerous working elements, depending on their purpose and process modes of their operation. Tillers with G-shape knives (Fig.1) have been the most common due to their universal nature, which allows for both deep, and shallow ripping of soil, incidentally cutting weeds, what is suitable for tilled crops.

An analysis and theoretical research into the operation of a G-shape tiller-type working element for secondary tillage have therefore been performed.

A G-shape knife contains a tine, cutting in the vertical plane, and a plate, bent at a $90^0$ angle to the tine. The knife can have the upper or lower grinding.

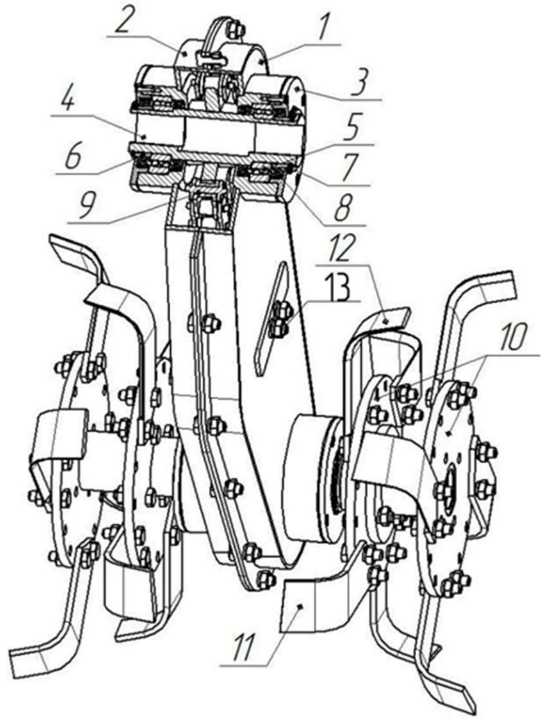


**Figure 1.** Gear box assembly with blades

1 – Half-case, 2 – Half-case, 3 – Cover, 4 – Sprocket; 5 – Bearing 1211, 6 – Bushing, 7 – Retaining ring, 8 – Collar 65x90, 9 – Chain PR-25.4-6000, 10 – Flanges, 11 –Left blade, 12 – Right blade; 13 – Cramp

Maximum depth of soil cultivation depends on the optimal depth of sowing: wheat – 2…4cm; corn – 4…5cm; sunflower – 3…4cm. Considering that the depth of embedding plant residues must be below the depth of forming a seed layer, let us assume that the depth of soil cultivation is equal to 10cm.

When working with soil, resistance is composed of the resistance to tearing-off soil slices in the horizontal direction by a knife's wing, and vertically cutting a layer by a knife's tine, the resistance to tearing off soil slices from the solid mass, plus imparting some speed to the cut mass (Nesterov, 2011). As per the formula of academician V.P. Goryachkin, the thrust force is determined as follows:

$$P = P_{fr} + P_c + P_{thr} \quad (1)$$

where $P_{fr}$ – resistance, caused by the friction of a knife with soil; $P_c$ – resistance to cutting from deformation of cut slices; $P_{thr}$ – force, required for imparting speed to the soil thrown by a knife.

$$P_c = P_1 + P_2 \quad (2)$$

where $P_1$ – force of resistance to cutting with a knife's tine; $P_2$ – resistance to cutting with a knife's wing.

A determined resistance to friction, caused by the contact between a knife and soil, can be combined with the second component.

The force of resistance to cutting with a knife's tine shall be defined by the formula:

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$$P_1 = k_{sp}\, h \tag{3}$$

where $k_{sp}$ – specific resistance to cutting with a blade, N/cm; h – depth of cutting, cm.

Professor A.D. Dalin had found that the specific cutting resistance in the damaged area on the soil surface is characterised by the cracks occurred near the open surface and it increases as the grinding angle of a tine's blade increases. An optimal angle of grinding lies within the 25–30° range.

The resistance force of a knife's tine is expressed by the following equation:

$$P = K_{sp}\, hb_t(1 + fctg\,\tfrac{i}{2}) \tag{4}$$

where $b_t$ – tine thickness, m; $f$ – friction coefficient; $i$ – grinding angle, degr.

When grinding angle $i$ declines to zero, resistance increases since friction forces increase. In loose soil with high friction coefficient $f$, angle $i$ will be wider as compared to small $i$ in the cohesive dense mass.

It is evident from the materials of V.A. Shamotov and V.S. Surikov that the resistance of a knife's tine and wing differs. For G-shape working elements, a tine consumes most energy (30–40%) during operation, and a wing consumes only 20–25%. 40–48% of energy is expended to tearing off soil slices along the side surface.

The knife wing resistance force shall be expressed from the following function: (Aushev, 2014; Gorbachev, 2013):

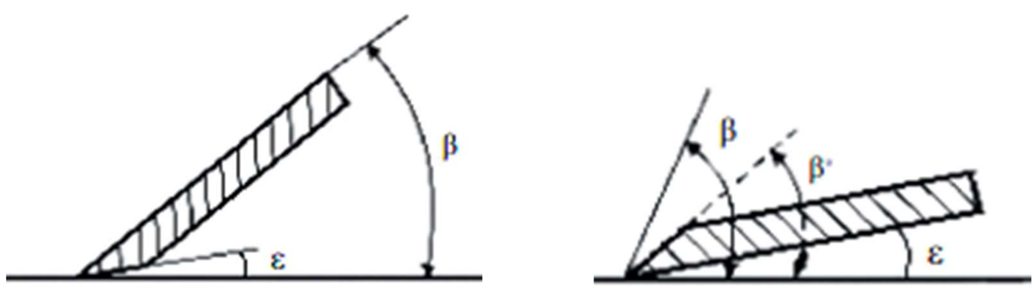
$$P_2 = f(l_{av}, b_H, k_{sp}) \tag{5}$$

where $b_н$ – width of the wing grasp, m; $l_{av}$ – average length of the arc of a cut soil element, mm; $k_{sp}$ – specific resistance to cutting in an arc.

Wings of G-shape working elements of tillage machines constitute dihedral, and trihedral wedge varieties.

Dihedral wedge can have lower and upper grinding.

The minimum value of angle β of the wedge with lower grinding of the blade must be equal to about 25° (Fig.2, a), if angle β<25°, there must be upper grinding (Fig.2, b).




a) b)

**Figure 2.** Section of dihedral wedge: *a* – with lower grinding; *b* – with upper grinding

In case of upper grinding, angle β° defines penetration ability of the wedge, since deformation and dynamic resistances of soil are applied to the wedge surface.

At the high values of crushing angle β (wedge with upper grinding), the layer ceases to slip upward along the working wedge surface and starts to pile up ahead of the wedge. Such a phenomenon arises in cases when the sum of friction and crushing angles exceeds 90°, i.e. $\varphi + \beta > 90°$.
In this case, force *P* of wedge pressure on the layer is directed horizontally. This force compacts the soil ahead of the wedge. Compaction increases as the wedge moves forward until the soil disintegrates.
At the low values of crushing angle β (wedge with lower grinding), when $\varphi + \beta < 90°$ ratio takes place, the direction of force *P* disagrees with the direction of forward wedge motion, and forms angle ξ with it.
Such a direction of force *P* facilitates deformation of soil ahead of the wedge through tearing off, rather than shear (Fig.3). In this case, the wedge tends to tear off arm *ABO* from the furrow bottom, bend, and shift it.

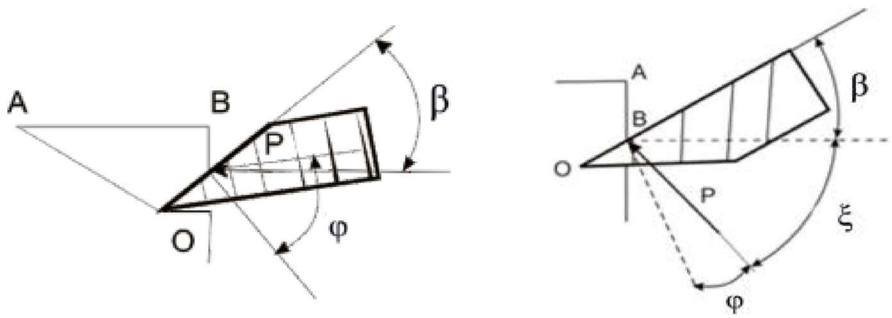



**Figure 3.** Effect of wedge on soils at various angles β:
*a* – at the wide β; *b* – at the narrow β

To ensure strength of the blade, a wedge angle must be equal to 15°–20°. Angle ε must not be narrower than 10°, since in this case, machine runs unsteadily in depth. The minimum value of angle β for the wedge with lower grinding of the blade, must be about 25°.
Deformations of soil, arising under the action of trihedral wedge, are similar to those due to dihedral wedge. The difference is that soil is crushed due to its cleavage or breakage, what increases energy intensity of the process.
A.D. Dalin was the first to analyse the conditions of throwing away a soil element (Fig.4), on which two forces, i.e., gravity force *mg* and centrifugal force $\frac{mv^2}{R}$, act.

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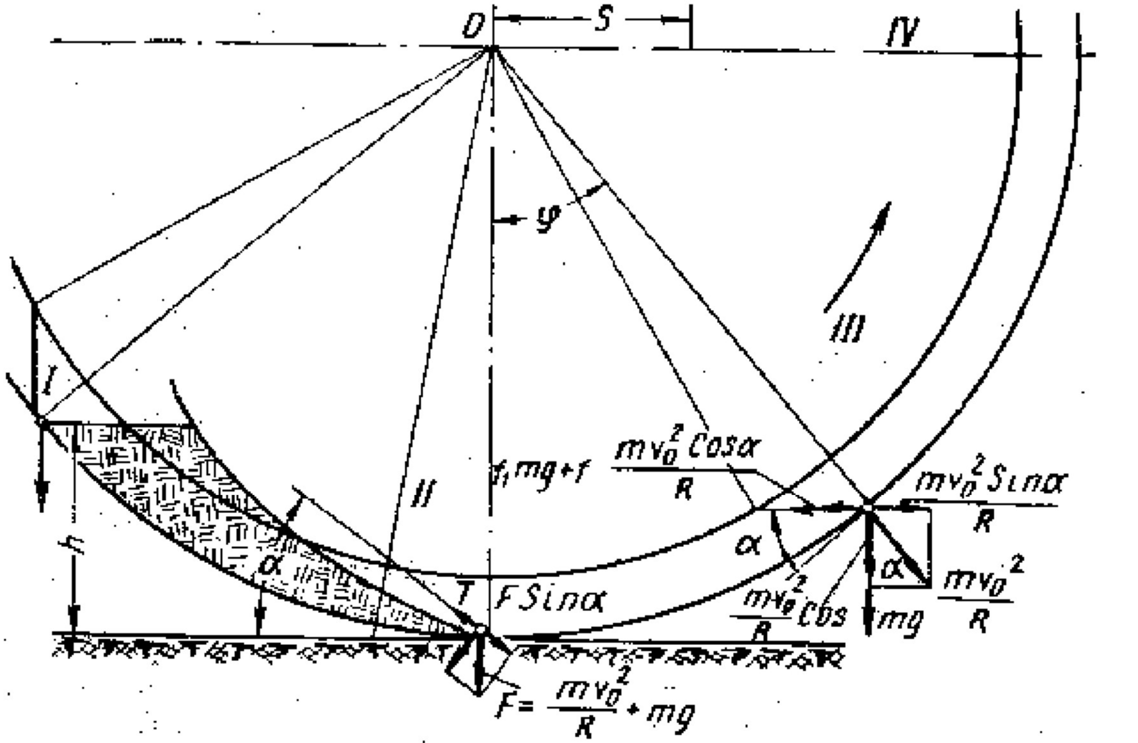


**Figure 4.** Forces acting on a soil particle, when it is thrown down a tiller field hook:
I – IV – position of a working element in the space

A condition, when the forces, acting on a particle, are in equilibrium, is as follows:

$$\frac{mv_o^2 sin\alpha}{R} \geq fmg\frac{fmv_o^2 cos\alpha}{R} \qquad (6)$$

where $m$ – weight of a soil particle, kg; $v_o$ – circumferential speed of a knife, m/sec; α – cutting angle, degr.; $R$ – radius of the knife end rotation, m; $f$ – friction coefficient; $g$ – gravity acceleration, m/sec$^2$.

Resistance to throwing away $P_{th}$ shall be expressed using the following formula:

$$P_{th} = \frac{75 \cdot bav_a^2}{2g} k_{th}^2 \mu \qquad (7)$$

where $b$ – thickness of cut slices, m; $a$ – width of a wing, m; $v_a$ – speed of particle movement, m/sec; μ – soil density, kg/m$^3$; $k_{th}^2$ – coefficient of soil particle.

The distance of throwing particles away is influenced by the knife cutting angle; it reaches its maximum at a 60-70° cutting angle. A rise in the knife width also enhances the distance, to which the soil is thrown away. The amount of thrown soil increases as the knife surface area increases and feed decreases.

It has been found that the weight of thrown soil, the distance, and the work done for throwing away increase as the tiller diameter increases. A change in the tiller diameter from 320 to 560mm increases the weight of thrown soil by 8.8% and the distance of throwing away by 57%.

## 3. Results and discussion

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Rotary tillage of soil is used to remove weeds, uniformly mix fertilisers with soil, create a fine-cloddy structure of a rippable layer. Due to high-quality breaking up and mixing of genetic horizons, rototillage provides a greater permeability of soil, enhances its microbiological activity and intensity of “breathing”, creates deep-laid deposits of moisture. Rotary tillage intensifies nitrification processes in the soil, creating favourable conditions for mineral nutrition of cultivated crops. A technological procedure of cutting soil with the working elements of rotary tillers as such implies separation of soil slices from the soil mass and throwing it away in the direction of tiller rotor rotation, as it is shown in Figure 5.

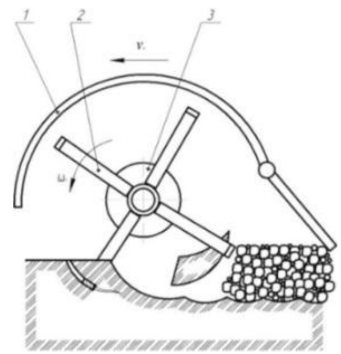


**Figure 5**. Technological procedure for cutting soil with working elements of tillers:
1 – protective casing, 2 – G-shape blades, 3 – tiller rotor, $\omega_0$ – angular speed of a tiller rotor, v– forward speed of a tiller

When cutting firm soil, the top slices of soil, which amount to about 30% of the total volume of cut soil, are thrown away at a 10-30° angle to the horizon.
When a tiller rotor operates, certain constraints are imposed on a speed operation mode, since as the number of rotations of a tiller rotor rises, the soil strata can be involved in circular rotation and thrown forward along the path of the unit motion (Fig.6). Gravity force $G = mg$, centrifugal force of inertia $F_c = mR\omega^2$, normal reaction $N$ of the knife surface, and friction force $F = fN$ act on a soil slice element.

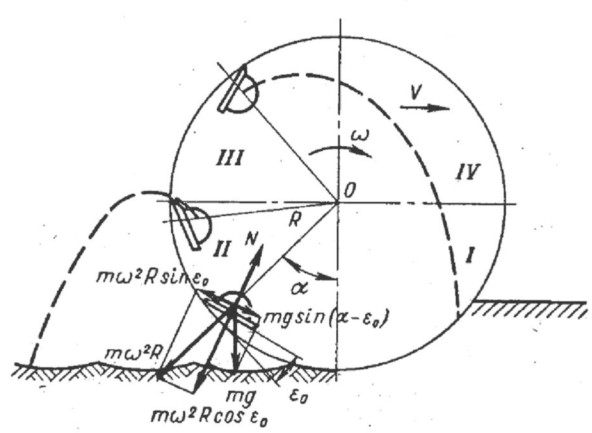


**Figure 6.** Forces, acting on the element of slices on the knife
Force, shifting the soil element downward from the knife:

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$$P_{sh} = mg\ sin\ sin\ (\alpha - \varepsilon_0) \quad (8)$$

Force, involving the element in rotation:

$$P_{inv} = fm[\omega^2 Rcos\ \varepsilon_0 + g\ soc(\alpha + \varepsilon_0)] + mR\omega^2 sin\ \varepsilon_0 \quad (9)$$

where $f$ – coefficient of soil friction with a knife; $m$ – weight of a soil slice element, kg; $\omega$ – angular speed of a tiller rotor, rad/sec; $\varepsilon_0$ – relief angle of a knife, degrees; $R$ – radius of a tiller rotor, m.

A slice element will start moving towards a rear edge of the knife if $P_{sh} > P_{inv}$:

$$mg\ sin\ sin\ (\alpha - \varepsilon_0) > fm[\omega^2 Rcos\varepsilon_0 + gcos(\alpha - \varepsilon_0)] + mR\omega^2 sin\varepsilon_0 \quad (10)$$

The value of the critical angle of stratum uplift is influenced by rotation frequency, friction coefficient, radius of tiller rotor, and knife blade angle:

$$n \leq \frac{30}{\pi}\sqrt{\frac{8[sin\ (\alpha_{\text{кр}} - \varepsilon_0) - fcos(\alpha_{kp} - \varepsilon_0)]}{R(fcos\varepsilon_0 + sin\varepsilon_0)}} \quad (11)$$

When rotary machine operates (11) on a plain surface and at a steady-state mode, power is equal to:

$$N = N_c + N_{thr} \pm N_{ov} + N_{rol} + N'_{\text{тр}} \quad (12)$$

where $N_c$ – power for cutting soil, kW; $N_{thr}$ – power for throwing soil away, kW; $N_{ov}$ – power for overcoming resistance $P_x$, kW; $N_{rol}$ – losses of power for rolling the machine, kW; $N_{fr}$ – losses of power in the machine gears, kW.

To determine the power for cutting and throwing away soil by tillers, G. Bernatskiy recommends proceeding from specific work $A_{sp}$:

$$N_c = \frac{1}{75} A'_c \alpha Bv = \frac{1}{75} k_c \alpha Bv \quad (13)$$

where $A'_c$– specific work of cutting, N/m$^2$; $B= bz_s$ - working width of the unit grasp; $z_s$ – number of knife sections of the unit, pcs.; $v$ – unit speed, m/sec.

$$N_{thr} = \frac{1}{75} k_{thr} \alpha B v^3 \lambda^2 \quad (14)$$

where $k_c$, $k_{thr}$ – cutting and throwing away coefficients have been obtained based on the experimental data of V.A. Yuzbashev.

Power to overcome resistance $P_x$ is:

$$N_{ov} = \pm P_X \frac{v}{75} = \pm Pcos\psi \frac{v}{75} \quad (15)$$

where $P_X$ – horizontal component of resultant resistance force $P$; $v$ – speed of a unit, m/sec; $\psi$ – slope angle of the resultant force, degrees.

Losses of power for rolling the machine:

$$N_{rol} = \mu' Q_z = \frac{v}{75} \quad (16)$$

where μ' – coefficient of resistance to carrying wheels' rolling; $Q_z$ – vertical load on carrying wheels, N.

Losses of power in the machine gears:

$$N'_{fr} = (1 - \eta_g) \cdot (N_c + N_{thr} + N_{ov}) \quad (17)$$

where $\eta_g$ – gear efficiency.

## 4. Conclusions

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Based on the foregoing and the results of field tests, carried out in 2021, we have developed an experimental specimen of the machine. In the "Scientific Production Centre of Agricultural Engineering" LLP, a research prototype of a combined unit for secondary tillage and sowing for tractors of a 0.6...14kN thrust class, FS-1.4 has been manufactured.

Evaluation of operation while preparing the topsoil to the depth of up to 10–12cm allowed us to draw the following conclusions:

- An increase in the speed of the unit motion decreases the degree of breaking up, whereas an increase in the rotation frequency of a tiller rotor raises it.
- As the rotation frequency of a tiller rotor rises, the specific energy costs for rotary tillage by G-shape knives increase more intensely than while rototilling by combined and straight knives.
- Combined and G-shape knives with R=0.04m bending radius demonstrate the best results in terms of the degree of crushing topsoil, at equal energy costs. A combined knife additionally rips tops of columns and increases the degree of breaking ploughed horizon up by 8–10%, hence it is worthwhile to use it in graded tillage.

Thus:

1. Theoretical dependence of specific energy costs for rotary tillage on the parameters, modes of tiller operation, and mechanical-and-physical properties of soil has been verified and confirmed by experimental studies.
2. With graded soil preparation, rotary tillage of topsoil with combined knives ensures high-quality ripping with the least specific energy costs, further disintegrating tops of columns and increasing the degree of breaking ploughed horizon up.

The practical significance of the scientific and technical project is to develop a combined tool adapted to the soil and climatic conditions of the Southern region of Kazakhstan for pre-sowing tillage and sowing seeds in order to increase their yield, reduce the cost of their cultivation, preserve and increase soil fertility.

The project is carried out within the framework of the budget program of the Ministry of Education and Science of the Republic of Kazakhstan 217 "Development of Science", subprogram 102 "Grant financing of scientific research" under the project: No. AP08053321 "Development of a resource-saving combined unit for pre-sowing tillage and sowing seeds on irrigated lands of the Southern region of Kazakhstan".

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